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Source Parameters from Identified Hadron Spectra and HBT Radii for Au-Au Collisions at $\sqrt{s_{NN}}$ =200 GeV in PHENIX

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The characteristics of the particle emitting source are deduced from low p_T identified hadron spectra ($(m_T - m_0) < 1$ GeV) and HBT radii using a hydrodynamic interpretation. From the most peripheral to the most central data, the single particle spectra are fit simultaneously for all $\pi^{\pm}$, $K^{\pm}$, and $\overline{p}/p$ using the parameterization in [1] and assuming a linear transverse flow profile. Within the systematic uncertainties, the expansion parameters T_{fo} and β_T, respectively decrease and increase with the number of participants, saturating for both at mid-centrality. The expansion using analytic calculations of the k_T dependence of HBT radii in [2] is fit to the data but no χ^2 minimum is found.

1. INTRODUCTION

Identified charged hadrons in 11 different centrality selections [3] and the transverse momentum (p_T) dependence of HBT radii in 9 k_T bins [4] are measured in Au-Au collisions at 200 GeV by the PHENIX Experiment [5]. In both the 200 GeV and previously measured 130 GeV data [6], the $\langle p_T \rangle$ of all particles increases from the most peripheral to the most central events and with heavier particle mass (m_0). The dependence of the $\langle p_T \rangle$ on m_0 suggests a radial expansion, and its dependence on the number of participant nucleons (N_{part}) may be due to an increasing radial expansion from peripheral to central events. The k_T dependence of the HBT radii was also observed and interpreted as a radial expansion.

Both the spectra and the k_T dependence of the HBT radii are fit using parameterizations based on a simple model for the source, where fluid elements are each in local thermal equilibrium and move in space-time with a hydrodynamic expansion [1,2]. The assumptions are: (1) no temperature gradients, (2) longitudinal boost invariance along the collision axis z, (3) infinite extent in space-time rapidity η, and (4) cylindrical symmetry with radius r. The particles are emitted along a hyperbola of constant proper time $\tau_0 = \sqrt{t^2 - z^2}$ and short emission duration, $\Delta t < 1$ fm/c.

The m_T dependence of the yield $\frac{d^2N}{m_t dm_t dy}|_{y=0}$ is calculated after integrating the source over space-time (azimuthal and rapidity coordinates) [1]. It is assumed that all particles decouple kinematically on the freeze-out hypersurface at the same freeze-out temperature

*For the full PHENIX Collaboration author list and acknowledgements, see Appendix “Collaborations” of this volume.

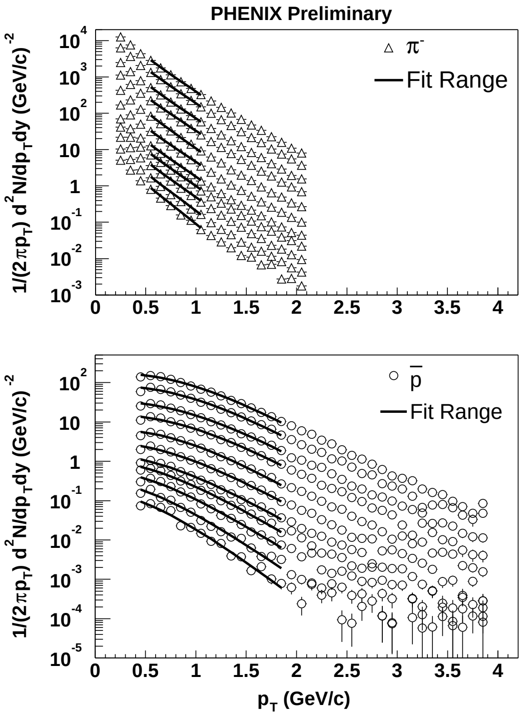

Figure 1. Simultaneous fits in the range $(m_T - m_0) < 1$ (solid lines) for π^- (top) and $\overline{p}$ (bottom) in all 11 centralities (scaled for visual clarity) [4]. The π resonance region is excluded in the fit.

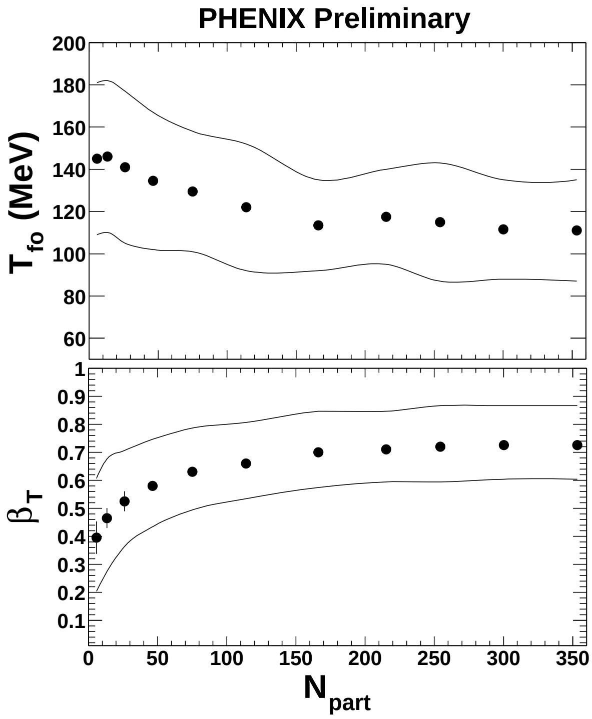

Figure 2. The expansion in each centrality. The top panel is T_{fo} and the bottom is β_T, both plotted as a function of N_{part}.

T_{fo}, and that the particles collectively expand with a velocity profile $\beta_T(r) = \beta_T r/R$ where R is the geometric radius, r is the transverse coordinate, and β_T is the surface velocity. (For a box profile, the average velocity is $\langle\beta_T\rangle = 2\beta_T/3$ [7]). The particle density distribution is assumed to be independent of the radial position in the fits to the single particle spectra. In the previous 130 GeV analysis [8], a Gaussian density profile increases β_T by $\approx 2\%$ with a negligible difference in T_{fo}, while a parabolic velocity profile increases β_T by 13% and T_{fo} by 5%.

We use analytic expressions to calculate the HBT radii [2]. A linear flow rapidity profile in the transverse plane is assumed and a Gaussian distribution is used for the particle density dependence on r. The parameters are the geometric radius R, the freeze-out temperature T, the flow rapidity at the surface η_T ($\beta_T = \tanh(\eta_\mathrm{T})$) and the freeze-out proper time τ_0.

2. RESULTS

2.1. Fitting the single particle spectra

In order to minimize contributions from hard processes, all m_T dependent particle yields are fit in the range $(m_T - m_0) < 1$ GeV. As resonance decays are known to produce pions at low p_T [9], we place a lower p_T threshold of 500 MeV/c on π in the fit. A similar approach was followed by NA44, E814, and other experiments at lower energies. In Fig. 1, π^- and $\overline{p}$ yields are shown as a function of p_T for each event centrality [4]. The top 5 centralities are scaled for visual clarity. The solid lines are the simultaneous fits in the limited p_T range. Similar results are obtained for $K^\pm$, π^+, and p yields.

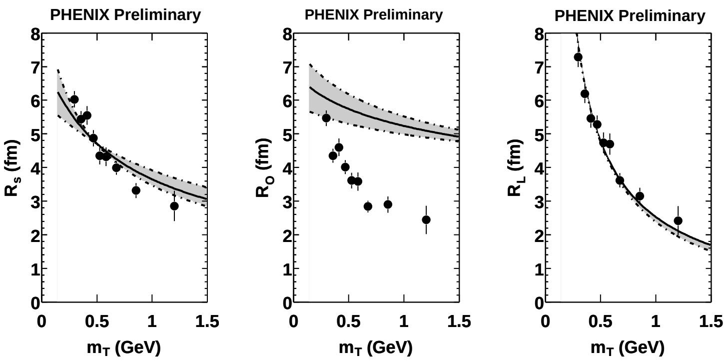

Figure 3. Constraining fits to $2\pi^-$ HBT radii in 10% central events using the expansion measured from the spectra. The shaded region is the systematic uncertainty from β_T and T_{fo}.

The systematic uncertainty in T_{fo} is determined by adding in quadrature the change in inverse slope due to the p_T dependent uncertainties in each particle yield at low p_T. For $\pi^{\pm}$, $K^{\pm}$, and $\overline{p}/p$, the uncertainty is ±10, ±13, and 16 MeV respectively. Added in quadrature, the total systematic uncertainty in the inverse slope is ±23 MeV. The systematic uncertainty in β_T is dominated by the uncertainty in the $\overline{p}/p$ spectral shape at low p_T and is determined by measuring the change in β_T after fitting for $p_T > 0.85$ GeV/c. The systematic uncertainty in β_T is 17.5%.

For the 5% most central events, particles are coupled to an expanding system with a surface velocity of $\beta_T = 0.7 \pm 0.2(syst.)$ and decouple at a common temperature of $T_{fo} = 110 \pm 23(syst.)$ MeV with negligible statistical errors. For the most peripheral events, $T_{fo} = 135 \pm 3(stat.) \pm 23(syst.)$ and $\beta_T = 0.46 \pm 0.02(stat.) \pm 0.2(syst.)$. The statistical error only is included in the fit, resulting in $\chi^2/dof = 260.9/52$ for the most central and 321.5/52 for the most peripheral events. At 130 GeV, similar results were obtained, with $\beta_T = 0.70 \pm 0.01$, $T_{fo} = 121 \pm 4$, and $\chi^2/dof = 34.0/40.0$ for the most central events (statistical and systematic errors are added in quadrature before the fit) [10].

The fit results of all particles within each event centrality are shown in Fig. 2. The top panel is T_{fo} and the bottom panel is β_T, both plotted as a function of N_{part}. Within the systematic uncertainties, the expansion parameters respectively decrease and increase with the number of participants, saturating at mid-centrality.

2.2. Fitting the k_T dependence of the HBT radii

The HBT radii are measured from identical charged π pairs in 9 k_T selections for 10% central events [5]. The systematic uncertainty in the data is 8.2%, 16.1%, and 8.3% for R_{s}, R_{o}, and R_{L}, respectively. A simultaneous fit to the HBT data could not be found over a broad range of parameter space. As an example, if the parameters β_T and T_{fo} are set to the values from the spectra analysis, then the fit to the HBT results constrains R and τ_0 from the R_{s} and R_{L} data respectively, yet the model overpredicts R_o by more than 3σ for all but the first m_T data point (Fig. 3). The systematic uncertainties in β_T and T_{fo} are represented by the shaded region. Within these boundaries, R ranges between $6.9 - 16.8$ fm and τ_0 ranges between $11.2 - 16.7$ fm/c.

The χ^2 contour levels of the expansion parameters T_{fo} (vertical) and η_{T} (horizontal) are shown for simultaneous fits to the spectra and separate fits to each HBT radius in Fig. 4. We note that no χ^2 minima are found, hence the contours are not closed. For the

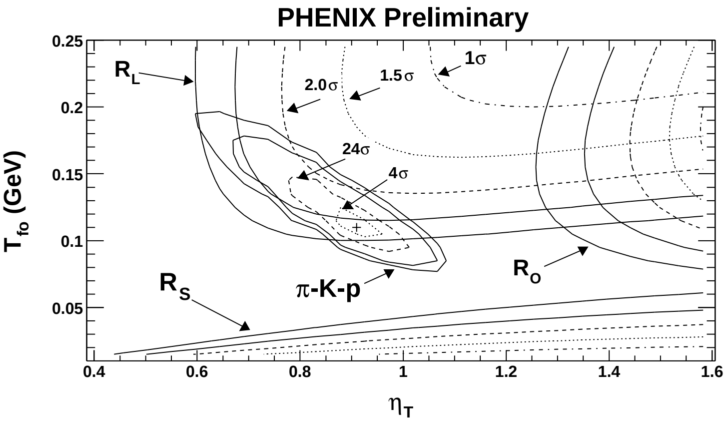

Figure 4. The χ^2 contour levels for the expansion parameters $T_{\rm fo}$ (vertical) and $\eta_{\rm T}$ (horizontal) after fitting $\pi^{\pm}$, $K^{\pm}$, $\overline{p}/p$ spectra and 2π HBT radii as indicated. Both scales are zero suppressed.

spectra, the contours are closed and show an anticorrelation, however there is no overlap with the HBT contours. The HBT radius $R_{\rm s}$ prefers large flow rapidity $\eta_{\rm T} > 1.0$ and low temperatures $T_{\rm fo} < 50$ MeV. The parameterization has the most difficulty reproducing $R_{\rm o}$.

3. CONCLUSION

The single particle spectra are qualitatively described by a hydrodynamic parameterization that assumes boost invariance and a linear transverse flow profile. The transverse expansion in 11 different centrality classes is extracted from the single particle spectra. Within the systematic uncertainties, the expansion parameters $T_{\rm fo}$ and $\beta_{\rm T}$, respectively decrease and increase with the number of participants, saturating at mid-centrality. Expressions for the HBT radii based on similar hydrodynamic assumptions and Gaussian density profiles do not describe the identical π pair data. Such fits worked well at CERN SPS energies [11], but fail at RHIC energies.

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